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The Experimental Study of the Effect of Cooling Pad Surface Shape on Passive Cooling Performance

Lohdy Diana[1 *], Arrad Ghani Safitra[1], Teguh Hady Ariwibowo[1], Ricko Guntur Riyantoni[1], Saiful Islam[1], Muhammad Fandi Setiawan Cahyono Prasetyo[1]

[1] Bachelor Program of Applied Engineering in Power Plant Engineering, Politeknik Elektronika Negeri Surabaya
Jl. Raya ITS, Keputih, Kecamatan Sukolilo, Surabaya, Indonesia-60111

*Corresponding author: lohdydiana@pens.ac.id
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Abstract

Climate change causes the air conditions inside buildings to increase in temperature. This causes the demand for cooling processes to increase every year. The use of cooling equipment currently requires quite a lot of electricity costs and produces CO_2 emissions. The experimental study of the effect of cooling pad surface shape on passive cooling performance to produce a cooling device that is economical and environmentally friendly. The variations of the cooling pad surface were sinusoidal wave and triangular wave. The method was experiments carried out in the laboratory to control environmental conditions. The test results showed that the sinusoidal wave variation had a temperature drop of 1.1 °C lower than the triangular wave. The sinusoidal wave variation has 5% lower relative air humidity than triangular wave variation but air humidity for both variations had increased. Meanwhile, the use of silica sand could not reduce air humidity, it was because of the sum of sand that was used.

Keywords: Passive Cooling, Energy, Temperature, Force Convection, Thermal.

1. Introduction

In general, climate change has begun to be felt. This impacts the air conditioning inside buildings, where most people carry out their activities. The building sector and community activities in buildings generated energy demand of around 32-48% of global energy demand, where the main energy consumption was allocated to cooling systems in the form of conventional HVAC (heating, ventilation and air-conditioning) [1]–[4]. This demand will continue to increase considering that in Asia, more than 50% of new buildings are built every year. The International Energy Agency predicts that electricity demand for cooling will reach 37% in 2016 and will continue to grow until 2050 [5]. The number of buildings, changes in airflow around the building, and the glass material in the building can increase the air temperature. This is because glass material has the property of transmitting solar heat into the building. The increase in air temperature inside the building results in the need for air cooling equipment in the form of AC (air conditioning), central AC, or AHU (air handling unit), which is not small; whose operation requires a large amount of electricity costs. On the other hand, it will produce CO_2 emissions. If the use of AC, central AC, or AHU is not reduced, the waste heat from these devices will also impacts the surrounding environment, causing the air temperature in the area outside the building to increase. One way to overcome this problem is by implementing green energy technology, one of which is the passive cooling system method. With the application of this method, it is hoped that energy savings and CO_2 emission reductions will be achieved by the energy conservation policy following PP No. 70 of 2009 [6].

Passive cooling in this research combined evaporation cooling and radiative cooling methods. Evaporation cooling is a cooling method that utilizes the process of evaporation of water to cool the air, The working principal scheme of evaporation cooling is as in Figure 1(a) [7]. Meanwhile, radiative

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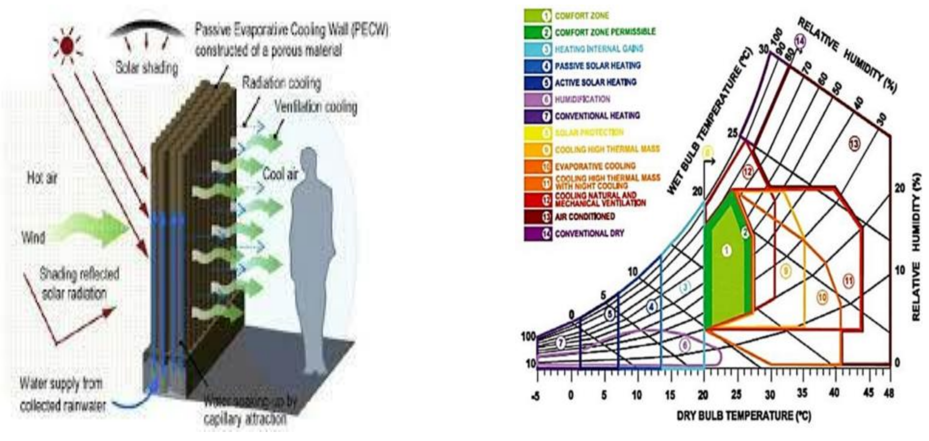
cooling usually occurs at night when the material stores cold so that it can reduce solar heat radiation the next day. A passive cooling system requires a component that functions as an air transmitter, called a cooling pad. Currently, the cooling pads that are often found are made from cellulose or organic fibers from plants. This research will use Innovative Materials to improve the cooling process. The innovative materials that will be used are combining new materials consisting of Phase Change Material (PCM) which is made from Paraffin, and Silica. The choice of these materials is because they have several advantages. Silica can control air temperature and air humidity [8]. Meanwhile, Phase Change Material (PCM) has the advantage of storing cold or heat according to the tool's intended use. PCM can be made from organic or non-organic materials [9].

This research hoped to produce the impact that this research could be used as an environmentally friendly and energy-efficient alternative cooling device that could meet cooling needs and was expected to increase the efficiency of energy use by reducing electricity costs spent on air conditioning. There were challenges faced by research such as high cooling loads or thermal comfort problems. Through this research, we would like to overcome challenges until the need for cooler spaces, reduced carbon emissions, or meeting standards can be realized. In this research, the prototype design would be adapted to conditions in Indonesia where during the summer, although the air temperature in Indonesia increases, the air humidity is still quite high because it is a type of tropical humid country [10]. Therefore, Silica material was needed which could absorb moisture so that the evaporation cooling method used could run optimally. The experimental study of the effect of cooling pad surface shape on passive cooling performance to produce a cooling device that was economical and environmentally friendly. The variations of the cooling pad surface were sinusoidal waves and triangular waves. The method was experiments carried out in the laboratory to control environmental conditions. The performance of passive cooling was characterized by air temperature decrease, air humidity, and saturation effectiveness parameter.

Psychometrics is a step to determine the comfort that is suitable for a room. Through psychometrics, the tools used can be selected appropriately so as not to disturb human comfort. The psychometric graph can be seen in Figure 1(b) [11]. Experimental testing was carried out to determine the reduction in energy consumption if the building insulation material used Aerogel. From the test results, it was found that Aerogel could reduce energy consumption by 18% when compared to those without insulation. This was caused by the very small thermal conductivity of the Aerogel, namely 0.014 W/m.K [12]. As technology developed, Aerogel was combined with fiber which was a composite fiber. This combination produced an Aerogel blanket or Aerogel sheet which could be used as an insulation material [13]. Experimental studies to determine the thermal characteristics of the Aerogel material were carried out and obtained results of changes in the standard deviation of the Aerogel temperature with variations in pressure [14].



(a) (b)

Figure 1. (a) Evaporation Cooling [7], (b) Psychometrics Chart [11]

Stone material is used as a ventilation medium [15]. However, with the development of technology, there are two types of natural basic materials, namely activated carbon foam and luffa pad, which is a natural fiber chosen to be used as a cooling pad. The material pad is then made to suit an

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evaporative cooling setup. Temperature and humidity are the most important data in this experimental analysis. Measurements were taken for each type of cooling pad using a data logger, the variation used was air flow rate. The results obtained from the test are the effect of cooling pad type on cooling efficiency. Based on test results, it was found that cooling pads made from carbon have better cooling efficiency when compared to cooling pads made from natural fibers [16]. Several studies on passive cooling have been carried out recently, such as the use of PCM for several cooling applications, for example, PCM was used as a filling material placed on the surface of window glass [17]. PCM was used to coat roofs, ventilation ducts, floors, ceilings, and walls. This aims to store cold energy [18], [19]. Silica gel has been proven to reduce air humidity. The test was carried out experimentally and the results obtained were a decrease in humidity (RH) towards [20], [21]. Apart from experiments, simulations were carried out to determine the temperature distribution of walls coated with Aerogel. Simulations were carried out to determine the speed of airflow and the air temperature in the classroom [22].

The saturation effectiveness of cooling pads was calculated using the following relation as mentioned in equation (1) below:

$$Eff_{sat} = \frac{T_1 - T_2}{T_1 - T_{1'}} \, x \, 100 \tag{1}$$

where T_1 is the dry bulb (DB) of air at the inlet, T_1' is the wet bulb temperature of the air at the outlet, and T_2 is the dry bulb temperature at the outlet [16].

2. Experimental Method

The passive cooling methods and techniques that will be used are evaporation cooling and radiative cooling. Evaporation cooling is a cooling method that utilizes the process of the evaporation of water to cool the air. The working principle scheme of evaporation cooling is as in Figure 1(a) [7]. Meanwhile, radiative cooling usually occurs at night when the material stores cold so that it can reduce solar heat radiation the next day. A passive cooling system requires a component that functions as an air transmitter, called a cooling pad. Figure 2 shows the passive cooling apparatus for this research.

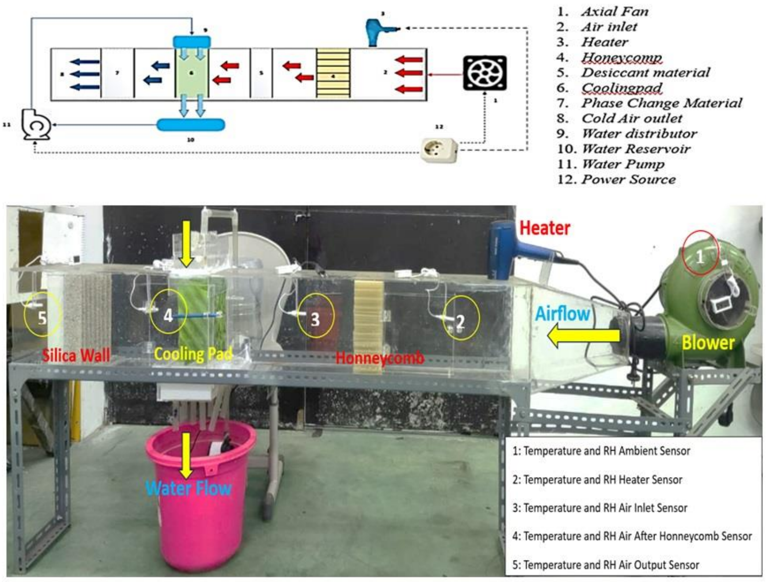

Figure 2. Passive Cooling Research Apparatus

In this research, the cooling pad used is made of fibrous fabric, as shown in Figure 3, with variations in the surface shape of the cooling pad, including sinusoidal and triangular wave shapes. The working principles of the passive cooling wall in this research include:

- Hot air from the environment enters through the cooling pad.
- Hot air will rub against the outer surface of the cooling pad.
- The air entering the cooling pad will be cooled with cold water flowing through the pump, and then water will be sprayed from the top of the cooling pad.
- PCM material is placed after the cooling pad to store cold.

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- The humidity of the cold air will be reduced by providing silica material.
- Cold air with normal humidity will come out through the passive cooling system and is ready to cool the room with the help of an induced fan.
- All parameters, including air temperature, humidity, and inlet air velocity, are measured.

The experimental testing procedure is as follows:

- Turn on the blower pump on the equipment and wait a few moments.
- Turning on the heater.
- After a while, turn on the heater to the lowest value.
- Turn on the water pump, then adjust the water flow so that the flow is looping (repeats).
- Wait for 5 minutes.
- Then take data on temperature (^{0}C), humidity (%), and wind speed (m/s).
- When finished, turn off the water pump on the equipment.
- Then turn off the heater on the equipment.
- The final step is to turn off the blower pump on the equipment.

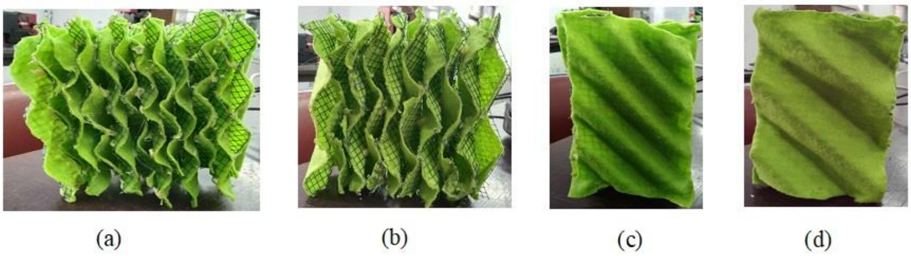

Figure 3. Cooling Pad Top View (a) Sinusoidal, (b) Triangular, Side view (c) Sinusoidal, (d) Triangular

The passive cooling apparatus needed many measuring instruments to take data parameters. The specification of the measuring instrument can be seen in Table 1 and the parameter setting can be seen in Table 2.

Table 1. Measuring Instrument Specifications

No.	Measurement Tool	Specification
1.	Thermometer	Indoor and outdoor -50 °C - +70 °C Temperature measurement precision ± 1 °C
2.	Humidity sensor	Humidity measurement range 10% RH-99% RH Humidity measurement precision ±5% RH Humidity resolution: 1%
3.	Anemometer	Range 0 – 30 m/s, resolution 0.1 m/s, accuracy ±5%

Table 2. Parameter Setting

No.	Parameter Setting	Value
1.	Air Environment Temperature	31 °C - 32.1 °C
2.	Air Environment Humidity	50% - 54%
3.	Air Inlet Velocity	1.1 m/s – 1.2 m/s
4.	Air Heater Blower Temperature	54 °C

3. Result and Discussion

Experimental testing was carried out in the laboratory. Data collection for each variation was conducted three times. After the experiments were completed, several parameters were obtained that would be analyzed to determine the effect of the cooling pad surface shape on passive cooling performance. Passive cooling performance was characterized by air temperature decrease, air humidity, and saturation effectiveness parameters. Experimental results for triangular wave variations are presented in Table 3, and sinusoidal wave variations are presented in Table 4. The results show that the sinusoidal wave-shaped cooling pad surface variation achieved the highest temperature decrease and

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humidity increase, namely 6 °C and 25 %, respectively. These values are slightly better compared to the triangular wave-shaped pad variation, which only achieved the highest temperature decrease and air humidity increase of 4.9 °C and 19 % respectively. This is because the sinusoidal wave pad variation has a more complex surface shape, providing a larger contact area that allows for optimal heat transfer due to the longer air residence time on the pad [23], [24].

3.1 Air Temperature Decrease

The decrease in air temperature was the difference in air temperature after passing through the honeycomb minus the output air temperature. Based on Table 3 and Table 4, both variations show the same results, namely that the air temperature has decreased. In the test results, the triangular variation has the largest temperature difference of 4.9 °C at the 50th minute, with an air temperature after the honeycomb of 38.8 °C and an exit air temperature of 32.7 °C. The sinusoidal variation has the highest temperature difference of 6 °C at the 45th minute, with the air temperature after the honeycomb 37 °C and the exit air temperature being 31.3 °C. The sinusoidal wave variation had a temperature drop of 1.1 °C lower than the triangular wave.

3.2 Air Humidity

The air humidity for both variations had increased. The triangular wave variation experienced an increase in average air humidity of 3.08%. Meanwhile, the sinusoidal wave variation experienced an increase in average air humidity of 7.58%. The sinusoidal wave variation has 5% lower relative air humidity than the triangular wave variation. This was still within the comfort threshold for the human body, namely around 50% - 60%. However, in its application, air humidity in passive cooling must be maintained so that it does not increase too significantly. This was because if the external environmental conditions had relatively high humidity, the humidity after passive cooling would increase. An increase in humidity that was too significant caused the air to condense into water and could wet objects around it. The increase in air humidity in the results of this experiment indicated that the amount of silica installed in passive cooling as a moisture-absorbing material was not optimal. Therefore, further studies are needed to determine the optimum amount of silica and placement position that can be applied to passive cooling devices.

3.3 Air Temperature

The water temperature on the outlet side decreased for all variations of the cooling pad. This indicated that the water cooling process was occurring. Based on the experimental results, the temperature of the water entering passive cooling continued to increase over time. This was because the system used for water is a closed-loop process, so the incoming water temperature had a difference from the initial incoming water temperature. Based on these results, passive cooling needed to be added to a cold storage system using certain materials, for example, phase change material. This aims to maintain a constant water temperature, which was expected to improve passive cooling performance.

3.4 Changes in Air Temperature Against Times, and Saturation Effectiveness

Changes in air temperature over time did not change too significantly. This was due to the unstable temperature of the incoming feed water. Meanwhile, passive cooling was expected to reduce air temperature over time. These results were in contrast to current research that air temperature change increases over time [16]. This could be due to the data collection taking less time in this research, and the water temperature had to be lower, or less than 22 °C for future experiments. It can be seen in the saturation effectiveness parameter, that both variations had relatively constant saturation effectiveness values. The result shows that passive cooling with sinusoidal waves cooling pad had 10 % higher saturation effectiveness cooling than triangular waves cooling pad, as can be seen in Figure 4.

Table 3. Experimental Results for Triangular Wave Cooling Pad

Triangular Wave Results Data (1)										
Minute to	Environmental Air	Air before Honeycomb	Air after Honeycomb	Air after Cooling Pad	Air Output	Water Inlet	Water Outlet	Air Velocity (m/s)	ΔT air (ºC)	ΔRH air (%)

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	T (ºC)	RH (%)	T (ºC)	RH (%)	T (ºC)	RH (%)	T (ºC)	RH (%)	T (ºC)	RH (%)	T (ºC)	T (ºC)	V (m/s)		
5	31.0	54	37.9	38	35.6	41	32.0	60	31.8	60	26.0	24.0	1.1	3.8	19
10	31.1	54	38.3	37	36.9	39	32.5	57	32.4	57	25.0	24.1	1.1	4.5	18
15	31.1	54	38.4	37	37.0	38	32.5	57	32.5	56	25.5	24.0	1.1	4.5	18
20	31.2	54	38.4	36	37.1	38	32.4	58	32.6	55	25.0	23.9	1.2	4.5	17
25	31.3	53	38.4	36	37.1	37	32.4	56	32.6	55	25.1	23.9	1.1	4.5	18
30	31.5	51	38.5	35	37.2	36	32.4	55	32.6	54	25.0	24.0	1.1	4.6	18
35	31.5	51	38.7	34	37.2	36	32.4	57	32.6	54	25.0	24.0	1.1	4.6	18
40	31.5	51	38.8	34	37.5	36	32.5	55	32.6	54	25.0	24.0	1.1	4.9	18
45	31.6	51	38.8	34	37.5	36	32.6	55	32.7	54	25.0	24.1	1.2	4.8	18
50	31.5	51	38.8	34	37.6	35	32.6	54	32.7	54	25.1	24.0	1.1	4.9	19
55	31.5	50	38.8	34	37.3	36	32.6	54	32.7	54	25.0	24.0	1.2	4.6	18
60	31.6	50	38.8	34	37.5	35	32.6	54	32.7	54	25.1	24.0	1.2	4.8	19

In the experimental Table 3 above, using triangular wave variations, the results of temperature changes, namely with delta temperature (ΔT), and humidity changes, namely with delta RH (ΔRH) are, compared between the air before the honeycomb and the output air. From the data above, the temperature is obtained 5 minutes after the device works, and then the measurement process is carried out at a delta temperature of 3.8 °C and a delta RH of 19 %. Furthermore, at a time of 10-60 minutes has a relatively similar difference: a delta temperature is 4.5 °C - 4.9 °C, and a delta RH is 18% - 19%. Whereas at 50 minutes, the biggest difference is obtained, reaching a delta temperature of 4.9 °C and delta RH of 19%.

In the experimental Table 4 above, using sinusoidal wave variations, the results of delta temperature and delta RH are compared between the air before the honeycomb and the output air. From the data above, the temperature is obtained 5 minutes after the device works, and then the measurement process is carried out at delta temperature of 5.1 °C and a delta RH of 20%. Furthermore, at a time of 10-60 minutes has a relatively similar difference: a delta temperature is 5.5 °C - 5.7 °C, and a delta RH is 20% - 22%. Whereas at 45 minutes, the biggest difference is obtained, reaching a delta temperature of 6 °C and delta RH of 25%.

Table 4. Experimental Results for Sinusoidal Wave Cooling Pad

Sinusoidal Wave Results Data (2)															
Minute to	Environmental Air		Air before Honeycomb		Air after Honeycomb		Air after Cooling Pad		Air Output		Water Inlet	Water Outlet	Air Velocity (m/s)	ΔT air (ºC)	ΔRH air (%)
	T (ºC)	RH (%)	T (ºC)	RH (%)	T (ºC)	RH (%)	T (ºC)	RH (%)	T (ºC)	RH (%)	T (ºC)	T (ºC)	V (m/s)		
5	31.8	52	38.0	38	35.8	41	30.6	62	30.7	61	22	24	1.1	5.1	20
10	31.9	51	38.6	37	36.8	39	31.0	61	31.3	59	22	24	1.1	5.5	20
15	32.1	52	38.8	37	37.2	39	31.3	64	31.6	60	23	25	1.2	5.6	21
20	32.1	53	38.8	37	37.2	39	30.9	62	31.5	59	22	24	1.1	5.7	20
25	32.1	53	38.8	37	37.3	38	31.3	61	31.6	59	22	24	1.1	5.7	21
30	32.0	54	38.8	37	37.3	39	31.4	62	31.6	60	23	24	1.1	5.7	21
35	31.9	53	38.8	36	37.2	38	31.5	62	31.7	60	24	25	1.1	5.5	22
40	31.9	52	38.8	35	37.3	37	31.5	64	31.6	59	24	25	1.1	5.7	22
45	32.1	52	38.8	35	37.3	37	31.4	64	31.3	62	23	25	1.1	6.0	25
50	32.1	51	39.0	35	37.4	37	31.6	60	31.9	59	23	25	1.1	5.5	22
55	32.0	52	39.0	35	37.4	37	31.6	61	31.9	59	24	25	1.1	5.5	22
60	32.2	50	38.9	35	37.5	37	31.7	62	32.0	59	24	25	1.1	5.5	22

Based on Figure 4, it can be seen that the saturation value of the effectiveness of cooling in the sinusoidal wave variation with a test time of 60 minutes has the greatest value of 48.7% at 45 minutes. while the saturation value of the effectiveness of cooling in the triangular wave variation with a test time

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of 60 minutes has the greatest value of 38.4% at 10 minutes. It can be concluded that the sinusoidal wave variation has a better saturation effectiveness of cooling compared to the triangular wave variation.

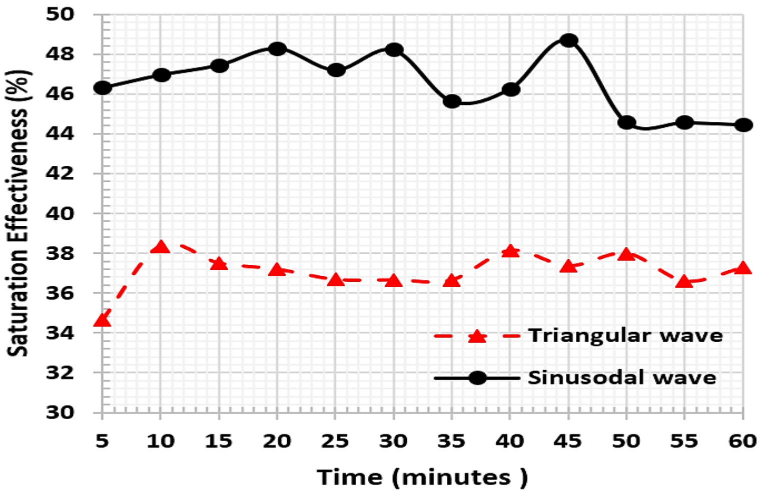

Figure 4. The Saturation Effectiveness of Cooling

4. Conclusion

The conclusion of this research consists of: The sinusoidal wave variation has a 1.1 °C lower temperature drop than the triangular wave. The sinusoidal wave variation had a 5% lower relative air humidity than the triangular wave variation, but the air humidity for both variations increased. The water temperature at the outlet side decreased for all cooling pad variations. The change in air temperature from time to time is not very significant. The cooling effectiveness is influenced by the cooling pad variation, the further the distance between the waves, the more the cooling effectiveness can be increased. Suggestions for further research are that further research needs to be done to determine the optimal amount of silica and placement position that can be applied to passive cooling devices. Passive cooling devices need to be added to the cold storage system.

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